# AIR-SEA TRANSFER MEDIATED BY SPRAY

Edgar L Andreas
U. S. Army Cold Regions Research and Engineering Laboratory
72 Lyme Road
Hanover, New Hampshire 03755-1290
Phone: 603-646-4436
Fax: 603-646-4644
eandreas@crrel.usace.army.mil

N0001497MP30003

## LONG TERM GOALS

The goal is to investigate, theoretically and through analyzing existing data, the role that sea spray plays in transferring heat and moisture across the air-sea interface. Ultimately, we hope to develop simple parameterizations for these air-sea fluxes for use in large-scale models.

## OBJECTIVES

The biggest impediment to progress in this area is poor knowledge of the rate at which sea spray droplets of various sizes are produced at the air-sea interface. Thus, the first objective is to better quantify the sea spray generation function. Two classes of spray droplets exist: those derived from bursting bubbles (either film or jet droplets) and those torn directly from wave crests by the wind (spume droplets). The spray generation function for each class likely depends on wind speed, water temperature, sea state, and surface contaminants. The second objective is to develop parameterizations, based on microphysical modeling, for the rate at which individual spray droplets exchange heat and moisture with their environment. The third objective is then to couple the spray generation function with the microphysical modeling to estimate the integrated contribution of all spray droplets to the surface heat and moisture fluxes. A related objective is to quantify how the feedback between the elevated spray heat and moisture sources alters the interfacial transfer (the turbulent air-sea transfer that obtains in the absence of spray).

## APPROACH

This work is theoretical and analytical; there has been no experimental component. Microphysical theory establishes how rapidly spray droplets can exchange heat and moisture in a given environment. Theoretical considerations also predict how the sea spray generation function should depend on wind speed. The analytical part involves developing parameterizations for the various processes under consideration by simplifying model results or by synthesizing various data sets and observations reported in the literature. Checking the parameterizations being developed against available data is also another aspect of what I call analytical work.

# Report Documentation Page

*Form Approved*
*OMB No. 0704-0188*



| | | |
|---|---|---|
| 1. REPORT DATE<br>**30 SEP 1997** | 2. REPORT TYPE | 3. DATES COVERED<br>**00-00-1997 to 00-00-1997** |

| | |
|---|---|
| 4. TITLE AND SUBTITLE<br>**Air-sea Transfer Mediated by Spray** | 5a. CONTRACT NUMBER<br>5b. GRANT NUMBER<br>5c. PROGRAM ELEMENT NUMBER |
| 6. AUTHOR(S) | 5d. PROJECT NUMBER<br>5e. TASK NUMBER<br>5f. WORK UNIT NUMBER |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br>**US Army Cold Regions Research and Engineering Laboratory,72 Lyme Road,Hanover,NH,03755-1290** | 8. PERFORMING ORGANIZATION REPORT NUMBER |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | 10. SPONSOR/MONITOR'S ACRONYM(S)<br>11. SPONSOR/MONITOR'S REPORT NUMBER(S) |

12. DISTRIBUTION/AVAILABILITY STATEMENT
**Approved for public release; distribution unlimited**

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT<br>**unclassified** | b. ABSTRACT<br>**unclassified** | c. THIS PAGE<br>**unclassified** | **Same as Report (SAR)** | **4** | |

**Standard Form 298 (Rev. 8-98)**
Prescribed by ANSI Std Z39-18

A lot of work has been done on the physics of air-sea interaction and the details of the atmospheric surface layer above the sea surface. None of this work, however, has shown conclusively that spray affects air-sea exchange. But few measurements have been made in winds above 20 m/s, where my modeling suggests that spray finally becomes a significant transfer mechanism. Consequently, another aspect of my approach is to make certain that predictions from my spray model are compatible with previous observations of air-sea heat and moisture fluxes.

## WORK COMPLETED

The spray generation function that I developed (Andreas, 1992) has yielded useful results (e.g., Fairall et al., 1994) but is limited to wind speeds of 20 m/s or less. I have, thus, developed a new spray generation function, based on the model reported in M. H. Smith et al. (1993), that treats winds up to 32 m/s. That is, this new model can predict spray generation in winds of almost hurricane strength, where the hurricane community (e.g., Emanuel, 1986, 1997; R. K. Smith, 1997) has long been invoking an unidentified source of latent heat to maintain hurricanes. I have submitted a manuscript describing this new spray generation function (Andreas, 1997) and am currently revising that in light of reviewer comments.

The difficulty in identifying sea spray's contribution to the air-sea heat and moisture fluxes is that this contribution is not predicted to be larger than the signal-to-noise ratio of eddy-correlation measurements for those fluxes until the wind speed reaches at least 15 m/s (Andreas, 1992; Andreas et al., 1995). Because of the difficulty in measuring the turbulent fluxes at sea in such winds, there is thus scanty data with which to test the theory. The flux data collected in the North Sea during HEXOS (Humidity Exchange over the Sea Experiment; DeCosmo et al., 1996) is one of the few sets with any flux measurements in winds above 15 m/s. Janice DeCosmo and I (Andreas and DeCosmo, 1997) reported our preliminary analysis of her data in the context of my spray model with the purpose of looking for a sea spray signature in the HEXOS heat fluxes.

To treat the ultimate goal of my spray research—parameterizing spray effects for use in large-scale models—Jim Edson and I have completed a preliminary comparison of our individual spray models in two case studies (Edson and Andreas, 1997). Edson's model is fairly complex and computationally intensive; mine is less so. If results from the two models can be made to agree (they could), a simplified version of my model becomes a candidate for use in large-scale models.

## RESULTS

An implicit theme in this work is learning how the total air sea fluxes of sensible ($H_{s,tot}$) and latent ($H_{L,tot}$) heat partition between spray and turbulent (or interfacial) contributions. That is, eddy-correlation instruments positioned above the droplet evaporation layer (Andreas et al., 1995; say at 10 m) would measure $H_{s,tot}$ and $H_{L,tot}$, which actually result from both the interfacial sensible ($H_s$) and latent ($H_L$) heat fluxes and the spray sensible ($Q_S$) and latent ($Q_L$) heat fluxes. I am attempting to quantify this partitioning as

$$H_{L,tot} = H_L - \alpha Q_L , \qquad (1)$$

$$H_{s,tot} = H_s + \beta Q_S + (\alpha - \gamma) Q_L \ , \qquad (2)$$

where $\alpha$, $\beta$, and $\gamma$ are presumably constants of order 1.

A bulk flux algorithm such as the TOGA-COARE version (Fairall et al., 1996) of the LKB (Liu, Katsaros, and Businger, 1979) model is currently in vogue for predicting the turbulent fluxes $H_s$ and $H_L$. My spray model (Andreas, 1992) predicts $Q_S$ and $Q_L$. In the context of (1) and (2), the HEXOS data and the TOGA-COARE algorithm suggest $\alpha = \beta = \gamma = 3$ (Andreas and DeCosmo, 1997). But applying an alternative bulk flux algorithm—namely, Garratt's (1992)—to the HEXOS data suggests $\alpha = \beta = 0.5$ and $\gamma = 0$ (Andreas and DeCosmo, 1997). That is, Garratt's model automatically accounts for some of the spray effects and, thus, may be more accurate at high winds than the TOGA-COARE algorithm. In a third attempt to use (1) and (2) to partition the spray and interfacial fluxes, Edson and Andreas (1997) find $\alpha = \beta = 1$ and $\gamma = 0$. Here we used Edson's (Edson and Fairall, 1994; Edson et al., 1996) sophisticated spray model to predict $H_{s,tot}$ and $H_{L,tot}$, the TOGA-COARE algorithm (Fairall et al., 1996) to predict $H_s$ and $H_L$, and Andreas's (1992) spray model to predict $Q_S$ and $Q_L$.

In summary, if spray contributions were negligible—as they are currently assumed to be in all air-sea interaction models—we would have found $\alpha = \beta = \gamma \approx 0$ in these three sets of calculations. Because we did not, we suggest there is at last hard evidence that sea spray does mediate air-sea heat and moisture transfer for winds less than 20 m/s. For winds of hurricane strength, our models predict that spray dominates the air-sea transfer process.

## IMPACT

The TOGA-COARE bulk flux algorithm is widely presumed to be the best model for $H_s$ and $H_L$. I find, however, that though this may be the best model for the western equatorial Pacific, where the winds are generally light, it underestimates the measured HEXOS fluxes, which were obtained in higher winds. There are two ways to interpret this result. Either an alternative bulk flux algorithm, such as Garratt's (1992), has wider applicability than the TOGA-COARE algorithm, or another, unmodeled process—namely, transfer through sea spray—is coming into play at these higher wind speeds. In either case, the TOGA-COARE algorithm requires reevaluation.

My analysis suggests that sea spray becomes an important vehicle for transferring heat and moisture across the air-sea interface for winds above 20 m/s. In other words, as the winds approach hurricane force, sea spray plays an essential role in generating and maintaining hurricanes by providing the latent heat that modelers find necessary for maintaining these storms. That's why developing a simple spray parameterization for use in large-scale models is the ultimate goal of this research.

## RELATED PROJECTS

With Janice DeCosmo at the University of Washington, I have been reanalyzing her HEXOS data in light of my spray model (Andreas, 1992). I have also been working with Jim Edson of the

Woods Hole Oceanographic Institution on simplifying our respective sea spray models for use in large-scale air-sea interaction models. We, in fact, have a 2-year proposal currently under consideration at ONR to formalize and focus this research.

## REFERENCES


Andreas, E. L., 1992: Sea spray and the turbulent air-sea heat fluxes. *J. Geophys. Res.*, **97**, 11,429-11,441.

Andreas, E. L., 1997: A new sea spray generation function for wind speeds up to 32 m/s. *J. Phys. Oceanogr.*, submitted.

Andreas, E. L., and J. DeCosmo, 1997: Partitioning the air-sea heat fluxes into interfacial and spray contributions. Poster presented at Fifth Scientific Meeting of The Oceanographic Society, Seattle, WA, 1-4 April 1997.

Andreas, E. L., J. B. Edson, E. C. Monahan, M. P. Rouault and S. D. Smith, 1995: The spray contribution to net evaporation from the sea: A review of recent progress. *Bound.-Layer Meteorol.*, **72**, 3-52.

DeCosmo, J., K. B. Katsaros, S. D. Smith, R. J. Anderson, W. A. Oost, K. Bumke and H. Chadwick, 1996: Air-sea exchange of water vapor and sensible heat: The Humidity Exchange over the Sea (HEXOS) results. *J. Geophys. Res.*, **101**, 12,001-12,016.

Edson, J. B., and E. L. Andreas, 1997: Modeling the role of sea spray on air-sea heat and moisture exchange. Preprint volume, *12th Symposium on Boundary Layers and Turbulence*, American Meteorological Society, Boston, in press.

Edson, J. B., and C. W. Fairall, 1994: Spray droplet modeling: 1. Lagrangian model simulation of the turbulent transport of evaporating droplets. *J. Geophys. Res.*, **99**, 25,295-25,311.

Edson, J. B., S. Anquentin, P. G. Mestayer and J. F. Sini, 1996: Spray droplet modeling 2. An interactive Eulerian-Lagrangian model of evaporating spray droplets. *J. Geophys. Res.*, **101**, 1279-1293.

Emanuel, K. A., 1986: An air-sea interaction theory for tropical cyclones. Part I: Steady-state maintenance. *J. Atmos. Sci.*, **43**, 585-604.

Emanuel, K. A., 1997: Some aspects of hurricane inner-core dynamics and energetics. *J. Atmos. Sci.*, **54**, 1014-1026.

Fairall, C. W., J. D. Kepert and G. J. Holland, 1994: The effect of sea spray on surface energy transports over the ocean. *Global Atmos. Ocean Sys.*, **2**, 121-142.

Fairall, C. W., E. F. Bradley, D. P. Rogers, J. B. Edson and G. S. Young, 1996: Bulk parameterization of air-sea fluxes for Tropical Ocean-Global Atmosphere Coupled-Ocean Atmosphere Response Experiment. *J. Geophys. Res.*, **101**, 3747-3764.

Garratt, J. R., 1992: *The Atmospheric Boundary Layer*. Cambridge University Press, 316 pp.

Liu, W. T., K. B. Katsaros and J. A. Businger, 1979: Bulk parameterization of air-sea exchanges of heat and water vapor including the molecular constraints at the interface. *J. Atmos. Sci.*, **36**, 1722-1735.

Smith, M. H., P. M. Park and I. E. Consterdine, 1993: Marine aerosol concentrations and estimated fluxes over the sea. *Quart. J. Roy. Meteorol. Soc.*, **119**, 809-824.

Smith, R. K. 1997: On the theory of CISK. *Quart. J. Roy. Meteorol. Soc.*, **123**, 407-418.